

A stainless-steel mandrel for slumping glass x-ray mirrors

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ABSTRACT

We have fabricated a precision full-cylinder stainless-steel mandrel at Marshall Space Flight Center. The mandrel is figured for a 30-cm-diameter primary (paraboloid) mirror of an 840-cm focal-length Wolter-1 telescope. We have developed this mandrel for experiments in slumping—thermal forming at about 600°C—of glass mirror segments at Goddard Space Flight Center, in support of NASA's participation in the International X-ray Observatory (IXO). Precision turning of stainless-steel mandrels may offer a low-cost alternative to conventional figuring of fused-silica or other glassy forming mandrels. We report on the fabrication, metrology, and performance of this first mandrel; then we discuss plans and goals for stainless-steel mandrel technology.

INTERNATIONAL X-RAY OBSERVATORY

The International X-ray Observatory (IXO), next-generation astronomical X-ray Mission, requires extremely large collecting area (3 square meters of effective area at 1 keV and 1 square meter at 6 keV) combined with good angular resolution (5 arc-sec half power diameter) in order to achieve unprecedented sensitivities for the study of the high-z Universe and for high-precision spectroscopy of bright X-ray sources. Slumping glass technology is one of the fabrication techniques considered for producing the x-ray mirror segments for a single large x-ray mirror assembly. This mirror fabrication approach requires massive number of the forming mandrels. Stainless-steel mandrels may offer a low-cost alternative to conventional figuring of fused-silica or other glassy forming mandrels.

Stainless Steel Mandrel

Goal:

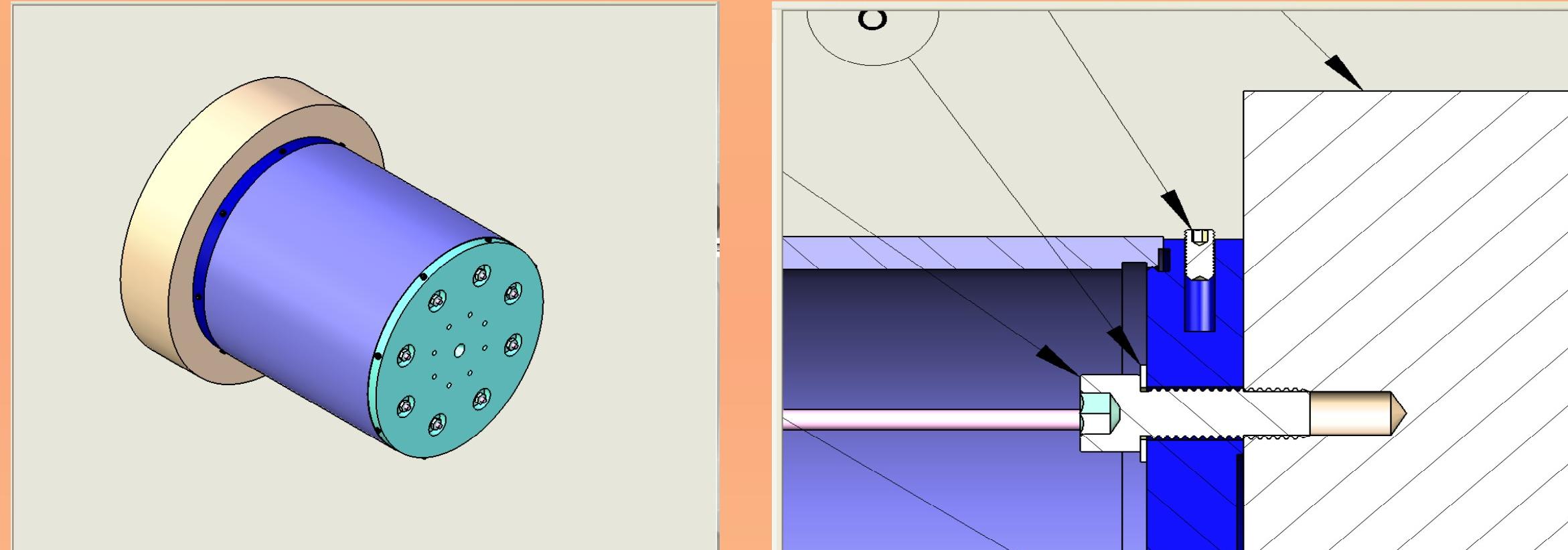
Find commercially available material applicable for manufacturing of the forming mandrels to significantly reduce cost of the glass replication process

Mandrel description

- 8400 mm focal length
- 155.080 mm intersection plane radius
- 304.8 mm overall length (12.000 inches)
- 200 mm optical length (50 mm zone at each end for polishing overstroke)
- Performance prediction requirement – 15 arc seconds (HPD)

Material: 304L Stainless Steel

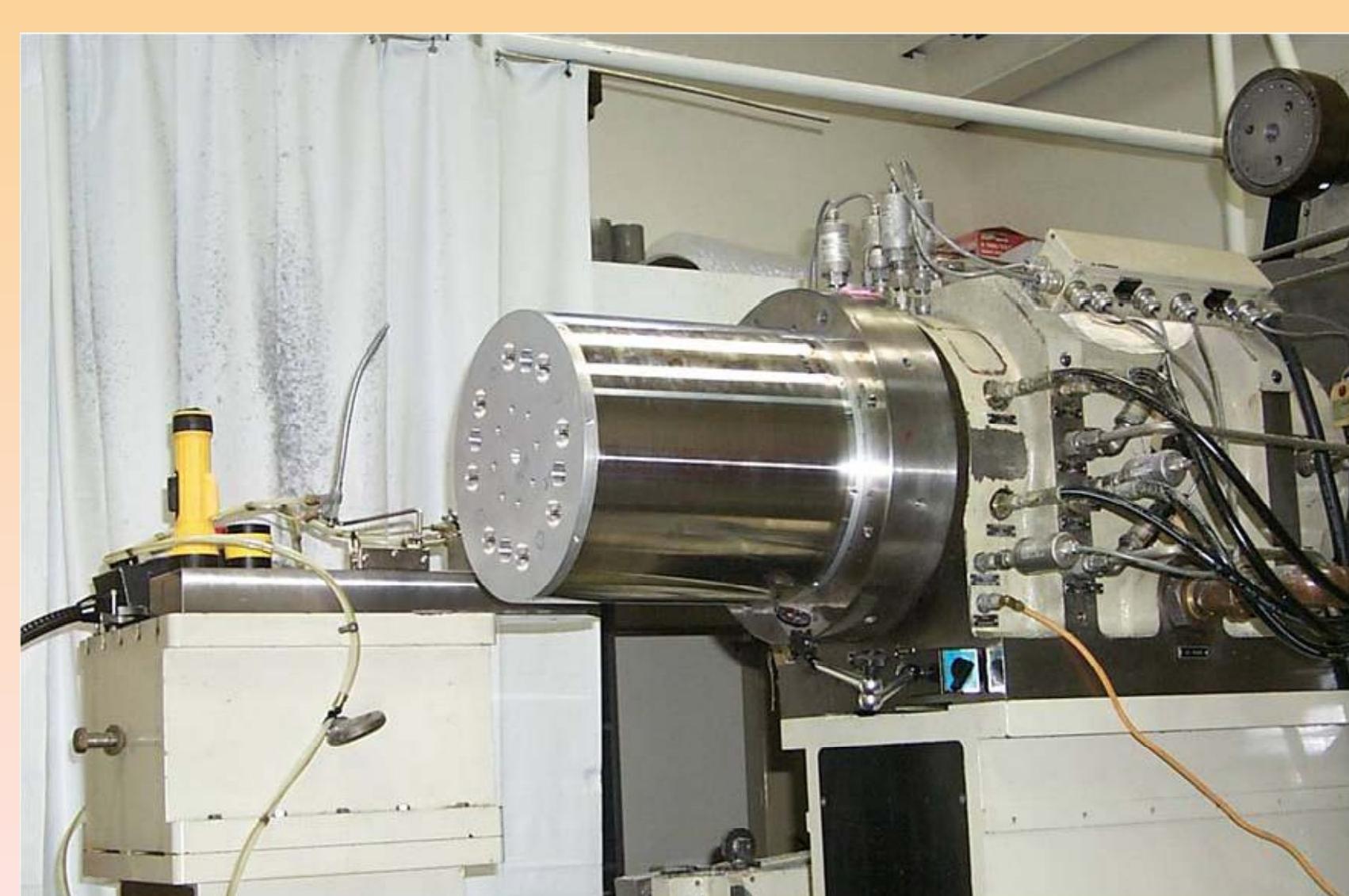
- 18-20% Cr, 8-12% Ni
- 0.03% C, 1% Mn, 1% Si, 0.045% P, 0.03% S, 0.1% other



Mandrel support design

Mandrel Fabrication

- Rough machining – Heat Treatment – Precise machining – Initial Precision turning – Axial Figure Metrology – Final Precision Turning – Polishing – Final Metrology
- Design of the support structures for machining, turning and polishing – Precision fit.
- Thickness of the mandrel was set to 1 cm based on thermal considerations.



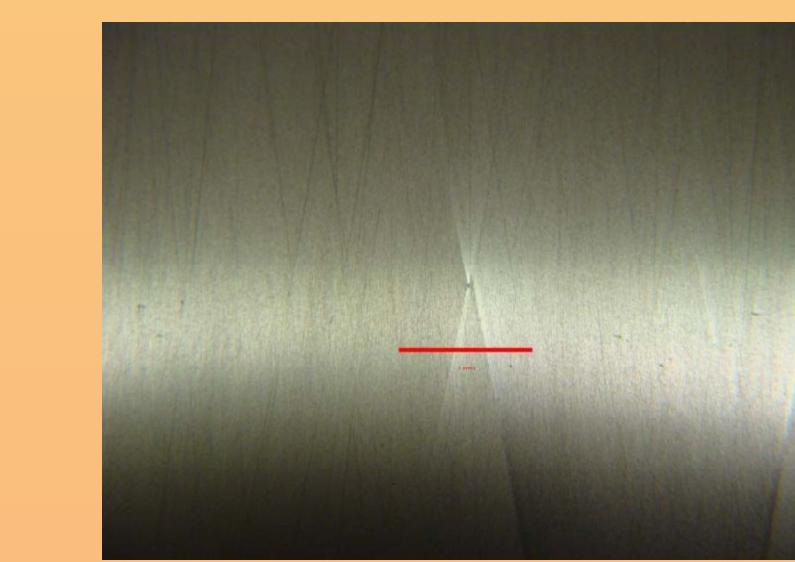
The mandrel on precision turning machine

Polishing:

- The hardened steel layer has appeared during initial polishing. The mandrel was precision grinded.
- At the point of final polishing pull-outs became visible (possibly the result of the precision turning)
- The mandrel was precision grinded again
- The mandrel is polished to 45A rms



Stainless Steel Mandrel at Coordinate Measuring Machine



An example of the mandrel surface "pull-ups"



The mandrel during the axial figure measurements using the Vertical long trace profilometer.

Metrology and Analysis

- Circularity Test Stand – for azimuthal variations of radius and cone angle
- Vertical Long Trace Profilometer - for axial slope deviations
- Coordinate Measuring Machine - for absolute radius and mean cone angle

Predicted Angular resolution (HPD), 2 reflections

Meridian	0°	45°	90°	135°	180°	225°	270°	315°	All 8
Axial HPD ₂ ["]	6.08	6.49	7.23	4.85	5.07	5.05	7.24	6.77	6.13
Cone HPD _{G2} ["]	6.39	1.49	3.93	1.25	2.57	4.93	6.80	3.75	7.28
Total HPD ₂ ["]	8.83	6.66	8.23	5.01	5.68	7.06	9.94	7.74	9.52

Surface Passivation



- Surface of SS coupon degraded during thermal cycling
- A surface passivation study has been performed. Two techniques have been tested: the electro-chemical passivation and nitric acid passivation.



Results:

Nitric acid passivated stainless steel coupon (left photo) – the surface roughness degraded from 46 to 168 Å after the heat treatment;

Electrochemically passivated stainless steel coupon (right photo) – the surface roughness degraded from 23 to 1068 Å after the heat treatment.

Future Plans

- Thermally cycle the mandrel. Perform full metrology on the heat treated mandrel to characterize possible changes in mandrels figure, circularity and surface roughness;
- Resume fabrication process study with coupons in order to define an ideal stainless steel for mandrel production;
- Produce hyperbolic mandrel to match the primary mandrel.